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PROGRAMMING

- USSR -

by M. R. Shura-Bura

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PROGRAMMING

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A numerical solution of any problem is the determination of the values of certain sets of functions of a finite number of variables -- the initial data of the problem. It is understood here that a certain final algorithm is defined for obtaining the values of the sought function from specified values of the arguments.

In order to solve the problem with the aid of various computational means, it is necessary in final analysis to formulate this algorithm in terms of the operations which can be performed with the aid of the means chosen. Such a description is, essentially, the program of calculations.

The need of compiling a program of calculations arose long before the appearance of so-called machines with program control. However, only with the appearance of these machines did quite substantial difficulties arise in the problem of compiling the program, and the entire problem as a whole was found to be deserving of special investigations in the development of method for its most rational solution. It is quite remarkable that the cause of the difficulties is not any shortcoming in modern universal digital machines, but more readily their tremendous capabilities.

Any algorithm can be described in terms of elementary operations of a universal machine. Any such description is formally a program for the solution of the corresponding problem. Were such a program applicable, then the problem of programming for automatic digital computers would reduce to the translation of a given algorithm into

the language of elementary operations of the machine. Even such a translation requires a certain expansion of the specified algorithm, since it is necessary here to take into account the distribution and the volume of the memory for numbers and commands, the impossibility of carrying out operations in many cases without fixing the intermediate results in certain memory cells, the fact that a new result cannot be written in the place of a quantity that is needed later, etc. This expansion of the initial algorithm could be formalized without particular difficulty, reducing thereby all the difficulties to the performance of purely technical work.

However, this method of "translating" is found to be essentially inconvenient. The point is that to realize any algorithm with the aid of a machine and its memory it is necessary to introduce all the initial information. For an automatic digital machine the concept of initial information includes information on the algorithm of solution, i. e., on the program. Therefore the time required for realization of the algorithm is known to be longer than the time consumed in the introduction of the program. In the case when the program introduced into the machine prior to solving the problem contains, in the forms of commands, all the elementary operations which must be performed to realize the algorithm, then the speed of performance of one elementary operation in solving the problem is limited by the speed of insertion of one command. For machines in which the time of performance of the command is many times shorter than the time of insertion of such a command to the memory of the machine, programs of this type are not acceptable.

In this connection the program should actually realize, in terms of elementary operations of the machine, a more general algorithm, which realizes, in addition to the specified algorithm of computations, certain auxiliary operations that insure the creation within the machine of commands for the performance of the given algorithm.

The work of Soviet mathematicians on problems of programming begun at the initiative of M. A. Lavrent'yev at the Institute of Precision Mechanics and Computational Engineering of the Academy of Sciences, USSR, where work has

been carried out in 1950, under the leadership of L. A. Lyusternik. The results of this work is the monograph of the staff of authors of Resheniye matematicheskikh zadach na avtomaticheskikh tsifrovykh mashinakh / Solution of Mathematical Problems by Automatic Digital Computers / (L. A. Lyusternik / 71 /, A. A. Abramov / 7 /, V. I. Shestakov / 5 /, and M. R. Shura-Bura / 7 /.)

The work of that time was made difficult by the lack of practical applications. It reduced essentially to thinking out real capabilities of the machine an investigation of various methods of programming.

When electronic computers came into being, a great impetus was obtained for the development of the entire trend. During the first period of the mastery of the new machines, the problem was of compiling programs for the realization of relatively simple algorithms.

The compilation of each such program is considered as a solution of an individual problem. The authors of the programs sought the most economic solutions, applying clever devices, unexpectedly using various capabilities of the machine. Unique competition arose on the improvement of various programs. In going over to the solution of more complicated problems there appeared immediately the impossibility of solving the problem of programming in such a manner. The growing number of programs and calculations had reduced the value of each clever solution of a particular problem and at the same time made it difficult to find such solutions. A more valuable property of a program under these conditions was simplicity, if not in the sense of size, then in the sense of uniformity of the steps employed in programming, i.e., methods of expanding the initial algorithm. During that period there took place a crystallization of the principal concepts and development of means of programming. The basic work was carried out at the Mathematics Institute imeni Steklov and at the Institute of Precision Mechanics and Computational Technology on the basis of two high-speed computers.

On the basis of the solution of the complicated problems, great difficulties appeared in the creation of a program without preliminary compilation of the so-called program

scheme -- a certain description of the algorithm in terms of sufficiently large operations.

The problem of programming breaks up quite clearly into two stages, the first of which is the choice of the expanded algorithm and its description in terms of sufficiently large operations, i.e., the compilation of the program scheme, and the second is the writing out of the large operations of the chosen expanded algorithm in terms of the elementary operations of the machine, i.e., with the aid of commands.

One of the causes of the difficulties that arise in programming is the fact that the complex algorithm has to be described in terms of relatively simple operations for the set of elementary operations in the machine. This circumstance leads to the need for dealing with a large number of commands and taking into account during the process of compiling the program all the still quite complicated connections and relations between the individual commands. It is quite obvious that programming would be much easier were the set of elementary operations of the machine to contain more complicated operations, for example, operations of calculation of values of certain elementary functions for the operation on vectors and matrices and in particular the operation of solving a system of linear equations and even more complicated operations. However, the capabilities of expanding the set of operations by apparatus means, even though not yet exhausted, are quite limited. At the same time the possibility exists of expanding the composition of operations by creating so-called standard sub-programs, which realize a certain frequently-employed algorithm. In the compilation of a new standard program it must necessarily be presented with the aid of the already available set of operations, among which, in addition to elementary operations of the machine, there may be contained also more complicated operations, performed with the aid of already prepared sub-programs. However, the operation which the new sub-program realizes can henceforth be considered as an elementary operation.

One of the important problems that arise in the compilation of a standard sub-program is the question of

choosing an economic algorithm. The tremendous speed, compared with manual, of operation of electronic computers makes it at first glance unnecessary to strive for choosing economic algorithms for various calculations. However, the need for solving ever more complicated problems has soon imposed on the programmers the question of ways of accelerating the computations, i.e., of finding more economic algorithms.

In particular, in solving an overwhelming majority of problems the need arises for multiple computations of values of elementary functions with a corresponding degree of accuracy. Even a superficial analysis of the role of these calculations in the solution of many problems indicates the possibility of substantial economy in the total solution time, provided a reduction takes place in the time required for calculation of the individual values of the elementary functions, primarily in the calculation of the values of square roots, exponents of functions, logarithm, and trigonometric functions.

From among the many works performed in this direction, worthy of note are those of V. S. Shtarkman, who perfected many standard programs for the "Strela" computer, the work of Ye. A. Volkov, who proposed new clever methods of computing certain functions and who compiled for the BESM machine many standard sub-programs, filling the fixed memory of the machine. Noticeable success in this direction was attained in recent years by the staff of the Computational Center of the Moscow State University, who improved substantially the constant sub-programs for the calculation of elementary functions on the "Strela."

The design of certain universal computers provides specialized devices, which are separate to one degree or another, for storage of sub-programs. These devices facilitate substantially the use of the small library of standard sub-programs and consequently the problem of working out a rational system of utilization of standard sub-programs, at least at the first periods of operation of the machine, is not as acute as in the operation of the machines without such specialized devices. It is therefore not accidental that the work towards creating a system of standard programs

was begun by the staff of the Moscow State University, N. P. Trifonov, Ye. A. Zhogolev, G. S. Roslyakov and others, in connection with the mathematical operation of the M-2 machine. The system created with the M-2 served later on as a base for the creation of a library of standard sub-programs for the "Strela" computer at the Computational Center of the Moscow State University. It is interesting to note that in connection with the M-2 machine, Ye. A. Zhogolev carried out in 1955 - 1956 investigations, worth of attention. on the singularities of programming on machines with fixed radix points, showing that the very widespread opinion of the exceeding difficulties of mathematical operation of such machines is greatly exaggerated. A method of floating scales, proposed by S. L. Sobolev and developed by Ye. A. Zhogolev, did not lead to any noticeable complication of the program, nor to an increase in time of solution of the problem compared with the solution with a machine with floating radix. The library of standard sub-programs for M-2 was compiled of two parts both for the fixed-radix mode, and for the floating-radix mode.

Along with standard sub-programs, which realize various computation algorithms, an important role in the operation of computational machines is played by the so-called servicing programs, intended for automatization of various processes of problem solution. An important place among such programs is occupied by programs which insure control over the correctness of the operation of the machine in the solution of problems. Thus, for example, the standard program produced in 1954 at the Mathematics Institute of the Academy of Sciences USSR, for the control of exchange of codes between various memory devices of the "Strela-1" computer has made it possible to increase the productivity of the machine by reducing the number of errors of the machine literally by several times. Later on analogous proggrams were compiled for all the "Strela" and BESM type machines. Worthy of note is the program for the automatic repetition of the count in order to control the operation of the machine, as compiled in the computational center of the Moscow State University.

The use of standard sub-programs results in substan-

tial economy in work on programming, but considerably expanding the elementary acts, into which it is necessary to breakdown the algorithm of solving the problem. However, the use of each standard sub-program in a specific problem requires a certain transformation of the subprogram, connected with the distribution of the memory and the presence of other sub-programs in the problem program. This transformation can be automatized to a considerable extent, i.e., can be entrusted to the machine.

Programs with which one realizes the necessary transformations, i.e., with which the individual sub-programs are composed into the entire program as a whole, are called compiling programs. In this connection notice should be taken of the program of adoption of internal addresses and the standard component program (SSP) for the "Strela" computer, produced in 1957, in the Computational Center of the Moscow State University by Ye. A. Zhogolev, and also the programming system of compiling type, developed in 1957 by the staff under the leadership of Yu. I. Morozov. Similar to the SSP in idea, but having greater universality, is the program of automatic adoption of addresses (PAPA), produced in 1956 by E. Z. Lyubinskiy and T. Isayenko. Another way of using the idea of standard sub-programs is the so-called interpreting method of programming, at which the standard sub-programs necessary during the course of realization of the algorithm are produced in the memory of the machine whenever the need for them arises.

Unlike in the foregoing compiling method, in the interpreting method, the problem of the distribution of memory is considerably simplified, since the sub-programs do not have to be stored in the memory of the machine simultaneously. L. V. Kantorivoch, L. T. Petrova, V. A. Bulavskiy and others in the Leningrad Division of the Mathematical Institute have been engaged since 1955 in the development of various interpreting programs, called by the authors "prorabs." An experimental verification of the work with prorabs has shown that the interpreting method in pure form is hardly applicable extensively owing to the many times increase in the machine time, required for the solution of the problems. Consequently further modernization

of the prorabls followed essentially the line of including in the system of a compiling method. An important feature of the system of programming developed by L. V. Kantorovich and others is the multi-dimensionality of the quantities, with which "prorab" is capable of operating.

No matter how perfect may be the methods of using the standard sub-programs, all presuppose the sub-programs themselves to be specified beforehand, i.e., compiled.

Therefore the method of standard sub-programs can in itself not lead to a complete automatization of the second state of programming -- the writing out of the expanded algorithm in terms of elementary operations of the machine.

For such an automatization it would be necessary above all to formalize the process of transition from the scheme to the program. The problem becomes complicated by the fact that a satisfactory transition can be considered to be only those methods, which would lead so to speak to "good programs," i.e., to good programs which are not inferior to those compiled manually. In addition, an unconditional requirement is the simplicity of the initial information compared with the program obtained as a result of the selected process. The first projects of compilation programs with the aid of machines suffered precisely from this shortcoming, since the information specified to the machine was differed little from the ordinary program not only in substance, but even in form. In this connection the process of compiling the initial information for the programming was also not easier than compiling the program itself.

The first serious advance in the direction of automatization of the second stage of programming is connected with the creation of the "programming program" PP-1 by E. Z. Lyubinskiy and S. A. Kamynin in 1954. The authors of PP-1 have placed before themselves the problem of formalizing and automatizing the transition from the so-called operator scheme to the program. The method described in the program with the aid of the operator scheme was proposed already in 1953 by A. A. Lyapunov. This method was found to be in most cases considerably more convenient than the method previously employed of the so-called block diagrams, and has immediately

won popularity. However, initially this method served only as a convenient means of describing the program or a sketch for their compilation. Later on the refinement of the concept of operator and the clear cut separation of the essential types of operators, the use of which can insure the compilation of a good program for an overwhelming majority of problems, has made it possible to use the operator scheme as a basic means for automatization of programming, more accurately speaking, of its second stage.

The operator scheme, the transition from which to the program is realized in the PP-1, was made up of operators of three types, namely logical operators P, forwarding operators F, and the so-called non-standard operators H. Contributing to the success of PP-1 was the new successful concept introduced by the authors of parameters and dependences of quantities on the parameters, and also the formalism they proposed of conditional numbers. A shortcoming of PP-1 was the fact that the initial information for the non-standard operators was essentially closer to the corresponding parts of the ready program.

The PP-1 program was kind of a model for verifying new ideas, which served as a base for the creation at the beginning of 1955 of a considerably more highly perfected programming program PP-2. This programming program was designed for the construction of a program in accordance with the operator scheme, in which there could be included, in addition to the operators PF and H, also the arithmetic operators O, the restoration operator O, and the reference operator Z. In the PP-2 there were realized the algorithms for writing down the formulas with the aid of commands, and also the algorithm for the economy of action in the working cells. Connected with the work on the PP-2 is the formulation of the problem on the economy of commands of forwarding, solved with the aid of an algorithm that realizes approximately the best economy.

Work on the creation of the PP-2 required the efforts of a large staff of programmers. In the work carried out under the leadership of M. R. Shura-Bura, there participated E. Z. Lyubinskiy, S. S. Kamynin, V. S. Shtarkman, E. S. Lukhovitskaya, I. B. Zadykhaylo, and others. An essential

feature of the PP-2 is the block principle of its construction, which permits, without reworking the problem to connect to it new parts, capable of processing the information in that case, when we desire to specify it in a new form, or else information pertaining to operators of new types. Thanks to such a construction, a block of differentiation and a new considerably improved block of adoption of true addresses, written by T. A. Trosman were later added on to the PP-2. At the present time work is being carried out on the block of sub-schemes.

The compilation of programs with the aid of a machine was the first serious use of the machine for "non-arithmetic" purposes. Work on the automatization of the programming made it possible to ascertain again the capabilities of the machine, and served as an impetus not only for the posing and solving of problems concerning other non-arithmetic uses of the machine, but also influenced the character of the computational programs, which were found to be more and more frequently non-arithmetic to a greater degree. Naturally, this made it possible to solve with machines many more complicated mathematical problems.

The success of the PP-2 has served as a stimulus for the creation of analogous programs on other high speed machines. Thus, in 1955 V. A. Fedoseyev compiled a programming program for the machine "Strela-2," and in 1956 A. P. Yershov did the same for the BESM machine, while N. A. Krinitskiy did likewise for the "Strela" machine. It must be noted that the authors of the new program did not copy the PP-2 blindly, but introduced perfections in the program, found new interesting algorithms, which realized various stages of writing out the commands, and also introduced new types of operators. An interesting feature of the program of A. P. Yershov was the fact that he included the cycle as a separate operator in the system employed by him.

Speaking of prospects of further automatization of the second stage of programming, mention should be made of the new programming program developed at the Computation Center of the Moscow State University, intended for use jointly with the method of standard sub-programs. There are grounds for assuming that it will be possible to automatize

most completely this stage of programming in this manner.

Automatization of the first step of programming, i. e., the choice of the expanded algorithm and its description in terms of operators of a given type, comes in contact with the problem of formalization of the transition from the initial algorithm to the expanded one. Attempts of a formal description of the program, undertaken by Yu. I. Yanov (1955 -- 1956), R. I. Podlovchenko (1956 -- 1957), and A. P. Yershov (1956 -- 1957) have still not led to any substantial steps in the desired direction. A successful solution of this problem is of considerable interest and could help in solving the problem of automatization of the first stage in programming.

The last stage in programming is work on the establishment of the correctness of the compiled program, the so-called "check-out," which reduces usually to detection and elimination of errors in the program. The check-out process for complex programs is very laborious and may, in the absence of auxiliary means, require a noticeable operating time of the machine. An automatization of this process is quite desirable. The automatization can be reached most completely with the aid of so-called control programs. Such programs are based on the idea of program simulation of the control device by a machine and on the concept of different control operations. In this connection, mention should be made of the work of E. Z. Lyubinskiy, S. S. Kamynin, and T. A. Trosman.

The highly perfected program of T. A. Trosman, compiled for the "Strela-1," served as a base for the creation of analogous programs on other machines. The accumulated experience in mathematical operation of universal digital machines was gained during the process of working on specific machines. There is therefore no doubt that the features of the existing machines exerted a definite influence on the development of methods of programming. However, very soon a reaction appeared whereby the development of the programmed methods began to influence the modernization of the available machines and the choice of constructions of new mathematical machines.

In the choice of a new construction it is very

important to estimate exactly the role and significance of various parameters of machine and its singularities. However, the experience of mathematical operation yields only a qualitative picture of the influence of various parameters and their singularities on the productivity of the machine. Therefore, statistical analysis of the operation of various devices of the machine during the conditions of solving the problems is of very great importance.

Interesting research of this type were carried out in 1956 -- 1957 by E. Z. Lyubinskiy and T. P. Kuznetsova, who obtained extensive statistical data, which served as valuable material in the solution of the problem concerning the rational choice of machine parameters.

To conclude this survey, it must be noted that it mentions by far not all the works on programming, carried out in the Soviet Union during the last seven years. We mentioned only those which, in the author's opinion, were representative of definite stages in development of the trend.

In estimating the results of work in the field of programming, we note the presence of serious accomplishments, particularly towards automatization. A serious shortcoming is the insufficient number of publications that expound the results of the research performed, and the brief communication on the work performed. At the present time measures are being taken to overcome this gap; one can hope that soon a systematic exchange of information by regular publication will be organized.

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